PCT
WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : C23C 14/35

A1

(11) International Publication Number: WO 96/21750

(43) International Publication Date: 18 July 1996 (18.07.96)

(21) International Application Number: PCT/US96/00409

(22) International Filing Date: 11 January 1996 (11.01.96)

(30) Priority Data:
08/372,023 12 January 1995 (12.01.95) US

(71) Applicant (*for all designated States except US*): THE BOC GROUP, INC. [US/US]; 575 Mountain Avenue, Murray Hill, New Providence, NJ 07974 (US).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): LEHAN, John, P. [US/US]; 927 Palace Court, Benicia, CA 94510 (US). BYORUM, Henry [US/US]; 910 Barstow Court, Sunnyvale, CA 94586 (US).

(74) Agents: PARSONS, Gerald, P. et al.; Majestic, Parsons, Siebert & Hsue, Suite 1450, Four Embarcadero Center, San Francisco, CA 94111-4121 (US).

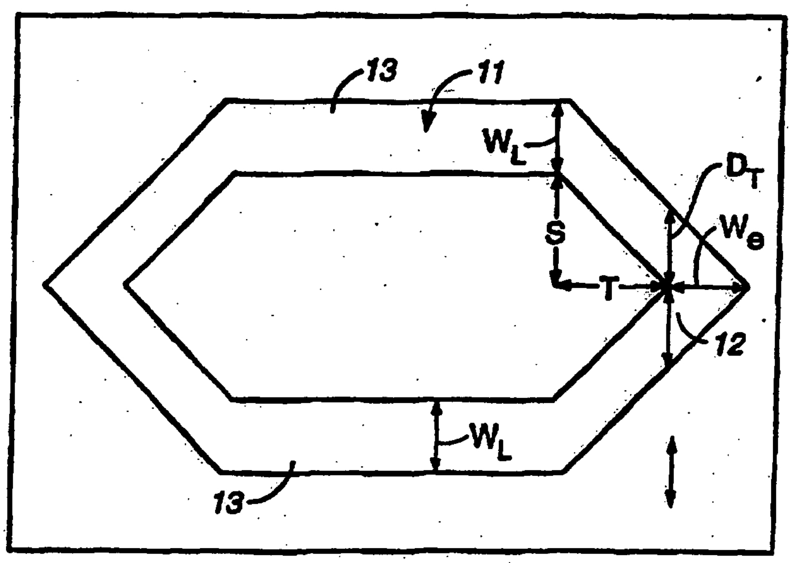
(81) Designated States: AL, AM, AT, AU, AZ, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, ARIPO patent (KE, LS, MW, SD, SZ, UG), Eurasian patent (AZ, BY, KZ, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: ROTATABLE MAGNETRON WITH CURVED OR SEGMENTED END MAGNETS

(57) Abstract

A magnetic assembly for a cylindrical magnetron is designed such that the racetrack (11) has an end section (12) shaped in a parabola, semi-ellipse, or triangle so as to reduce the erosion of the cylindrical target at the end portions. In this manner, the magnetic field at the ends of the racetrack need not be significantly reduced and the efficiency of the magnetron can be maintained.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AM	Armenia	GB	United Kingdom	MW	Malawi
AT	Austria	GE	Georgia	MX	Mexico
AU	Australia	GN	Guinea	NE	Niger
BB	Barbados	GR	Greece	NL	Netherlands
BE	Belgium	HU	Hungary	NO	Norway
BF	Burkina Faso	IE	Ireland	NZ	New Zealand
BG	Bulgaria	IT	Italy	PL	Poland
BJ	Benin	JP	Japan	PT	Portugal
BR	Brazil	KE	Kenya	RO	Romania
BY	Belarus	KG	Kyrgystan	RU	Russian Federation
CA	Canada	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic			SE	Sweden
CG	Congo	KR	Republic of Korea	SG	Singapore
CH	Switzerland	KZ	Kazakhstan	SI	Slovenia
CI	Côte d'Ivoire	LI	Liechtenstein	SK	Slovakia
CM	Cameroon	LK	Sri Lanka	SN	Senegal
CN	China	LR	Liberia	SZ	Swaziland
CS	Czechoslovakia	LT	Lithuania	TD	Chad
CZ	Czech Republic	LU	Luxembourg	TG	Togo
DE	Germany	LV	Latvia	TJ	Tajikistan
DK	Denmark	MC	Monaco	TT	Trinidad and Tobago
EE	Estonia	MD	Republic of Moldova	UA	Ukraine
ES	Spain	MG	Madagascar	UG	Uganda
FI	Finland	ML	Mali	US	United States of America
FR	France	MN	Mongolia	UZ	Uzbekistan
GA	Gabon	MR	Mauritania	VN	Viet Nam

ROTATABLE MAGNETRON WITH CURVED OR SEGMENTED END MAGNETS

Background of the Invention

The present application is a continuation-in-part of an application entitled "ROTATABLE MAGNETRON WITH CURVED OR SEGMENTED END MAGNETS", having serial number 08/372,023, with inventors John P. Lehan and Henry Byorum filed January 12, 1995.

The present invention concerns sputtering systems which use magnetrons to sputter off a target to form a coating on a substrate. In particular, the present invention concerns sputtering systems that use cylindrical magnetrons. Typical coatings that are formed with magnetron sputtering systems include thermal control coatings, architectural coatings and automotive glass coatings.

In a sputtering system, a plasma is formed in a partial vacuum of a sputtering chamber. Ions in the plasma are attracted to the target and cause some of the target material to "sputter" off the target. The gases used in sputtering systems can include inert gases, such as argon, for non-reactive sputtering. Alternately, reactive gases, such as nitrogen or oxygen, or a mixture of reactive and inert gases are used in reactive sputtering to form nitride or oxide layers. The target is typically a cathode with a high applied negative potential. Magnetrons are used to enhance the sputtering effect by containing the plasma near the target.

Planar magnetron systems form "racetrack" erosion zones in which only about 25% of the target material is eroded before the target must be replaced. Cylindrical magnetron systems can improve this target material utilization.

Cylindrical magnetron systems use a cylindrical target that is rotated around the magnetron. The rotation of the cylindrical target causes the erosion zone to be positioned on different locations on the cylindrical target at different times. Cylindrical magnetron systems are described in Wolf, et al, U.S. Patent No. 5,047,131 and McKelvey, U.S. Patent No. 4,356,073. Currently, 60% is a typical utilization rate of the target material in a cylindrical magnetron system.

Another prior art cylindrical magnetron system is discussed in Hartig et al., U.S. patent number 5,364,518. Figure 1 is adapted from Figure 5 of Hartig et al. This figure shows the plasma loop racetrack 115 of the Hartig patent. The width 118 of the end stretches 110 and 112 is made considerably wider than the width 120 of the strait stretches 114, 116. In order to do this, the magnetic field at the end stretches is reduced. The theory behind the Hartig et al. patent is that by widening the racetrack at the ends, the plasma should become less dense at these ends and the effect of end grooving in the cylindrical target should be reduced.

A problem with trying to produce a racetrack like that of figure 1 from the Hartig et al. reference is that the magnetic field at the end stretches must be drastically reduced in order to expand the width 118 sufficiently to eliminate the end groove. When the magnetic field at the end stretches is reduced the "magnetic bottle" effect of the magnetron is harmed.

Thus, less of the energy consumed by the device results in sputtering.

In some situations, the reduction of the magnetic field strength may be such that the system no longer works as a magnetron. Consider a magnetron which has a field strength of 300 gauss which is required for proper plasma containment at a working voltage of 400 V and a pressure of about 3 mTorr. The Larmor radius of an electron under these conditions is about 2 mm which is less than the 'dark space' for an unmagnetized Townsend discharge, and the plasma is stable. To produce the rectangular end track shown in figure 1, a reduction of the sputtering rate of less than one half would likely be necessary to result in an even groove after being integrated by the rotation of the cathode. The field strength would have to be reduced to about 120 gauss. The Larmor radius of the electron would be increased to about 6mm which is larger than the 'dark space' for an unmagnetized Townsend discharge, and the plasma is unstable in the regions of the reduced magnetic fields. The magnetron would no longer work as a high rate sputtering source. In short, reducing the end-track field strength sufficiently to expand the end regions 39 and 40 can result in a sacrifice of plasma stability.

It is desirable to increase the utilization rate of target material in cylindrical magnetrons in a manner that the magnetron device efficiency is maintained and the plasma remains stable.

Summary of the Invention

The present invention uses a magnetron that narrows the plasma racetrack at the ends in the direction along the rotation of the cylindrical target. This is done by optimizing the the the shape of the racetrack at the end portions and reducing the spacing

between the magnets while holding the field constant at the target surface. In this manner, the magnetic field need not be reduced in the manner required to produce the racetrack of Hartig et. al.

The invention preferably uses a field strength in the confining track which is kept constant over the length of the race track including the ends. The end portion of the racetrack needs to be controlled so that the erosion groove is kept to a constant depth over the whole sputtered surface. Since the cathode is rotated, the erosion is in effect integrated over each segment of the cylindrical surface. If the racetrack at the ends is longer than twice the width of the racetrack on the linear section then there will be more material sputtered off of the surface at the ends resulting in a deeper groove. An end geometry in the form of a circle or rectangle forms a racetrack significantly longer than twice the width of the linear section and consequently more material is sputtered from this region than is desirable.

The best end shape for the race track ends would be that of a triangle. When a triangle end is integrated there will not be extra erosion due to the rotation of the cathode because the apex of the triangle is not longer than the sum of the widths of the two linear sections.

In practice the apex of the end track becomes necessarily slightly rounded and there will be extra erosion at this end if not compensated by narrowing the racetrack width or reducing the field. Nonetheless, even if the racetrack width is not narrowed, the erosion will not be of the extent that occurs if the end track has a rectangular or circular shape. In practice, when the pole pieces are shaped according to the present

invention, the end shape approximates a parabola or semi-ellipse.

It is desired that the end portion of the racetrack be as "pointy" as possible. Thus, a triangular shape would be most preferable, if it was practicable. Additionally, a parabolic shape is more preferable than semi-ellipse shape. With the approximately parabolic shape obtained in practice, the erosion of the end of the target in a end portions of the cylindrical target is barely greater than that found over the linear portion even before adjusting the width of the racetrack.

A way to produce a "pointy" end portion of the race track is to shape the magnet section of the magnetron such that the magnet portions taper closer together in the ends rather than having a rectangular shaped outer magnet. This can be done by arranging the outer magnet section to include multiple rectangular magnets arranged in a tapering fashion, such as in a triangular shape. Alternately, the outer magnet section can be formed of a single magnet shaped into a tapering shape, such as a parabola.

Brief Description of the Drawings

Figure 1 is a diagram of a prior art racetrack for use with a cylindrical magnetron.

Figure 2A is a diagram of a racetrack shape of the present invention with triangular end sections.

Figure 2B is a diagram of a racetrack shape of the present invention with parabolic end sections.

Figure 2C is a diagram of a racetrack shape of the present invention with semi-elliptical end sections.

Figure 3 is a diagram showing a cylindrical magnetron.

Figure 4 is a diagram of a preferred embodiment of the magnetron for the present invention.

Figure 5A-C are diagrams of cross-sectional views of the magnetron shown in Figure 4.

Figure 6 is a graph of the tube radius versus position showing the erosion pattern of an embodiment of the present invention.

Figure 7 is a graph showing the erosion of a cylindrical target of the present invention.

Figure 8 shows a embodiment of the present invention in which the outer magnet is a cylindrical section whose plane projection looks parabolic.

Detailed Description of the Preferred Embodiment

Figure 3 is a diagram showing the cylindrical magnetron 30, with a magnetron portion 32, and target portion 34. A dotted line shows the position of a racetrack 36 which is defined by the magnetron 32. The racetrack 36 includes legs 36a and 36b, and an end section ,or "turn around" portion, 36c. The racetrack 36 is located at different portions of the target 34 as the target 34 rotates. Ions and electrons circulate along the racetrack 36 and the ions sputter off portions of the target 34.

The shape of the racetrack in the present invention can be best seen with respect to figures 2A-C. These figures are shown flattened out in order to clearly show the racetrack shape. In reality, the shapes will be along the surface of a cylindrical target.

Figure 2A is a diagram of a racetrack shape 11 of the present invention with triangular end sections 12. The longest distance, D_T, along the direction of rotation is given by the equation:

$$D_T = 2\,w_e\,\frac{W_L + S}{W_e + T}$$

Note that the larger the extension T, the smaller the value D_T and thus the lower the erosion in the end portions.. Additionally, the smaller the width W_e, the the smaller the value D_T and thus the lower the erosion in the end portions.

As shown in figure 2A, when the inner and outer portions of the triangular shape have the same slope, the distance, D_T, along the direction of rotation is equal to twice the width of the leg portions, $2w_L$. This means that even if the plasma density in the end portion 12 is the same as in the leg portions 13, 14, the erosion of the end portion 12 will be less than or equal to the erosion in the leg portions.

Looking again at Figure 1, the longest distance, D_r, along the direction of rotation is much greater than the leg widths in the rectangular racetrack configuration. If 2S is the separation distance between the leg portions then, $D_r = 2S+2w_L$.

Figure 2B is a diagram of a racetrack shape 16 of the present invention with parabolic end sections 17 and 18. The parabolic end sections 17 and 18 are more "pointy" than the circular end portions 20 ,21 shown in phantom. The longest distance, D_p , along the direction of rotation for the parabolic shaped end section is less than the longest distance, D_c , along the direction of rotation for the circular shaped end section shown in

phantom. Part of the reason for this inequality is that the parabolic end section extends more in the direction perpendicular to the rotation than the circular end section. That is T>S.

An equation for the longest distance, D_c, along the direction of rotation for the circular shaped end section is:

$$D_c = 2\sqrt{2SW_L + W_L^2}$$

In one embodiment of the present invention, the longest distance of the racetrack in the direction of rotation at the end portions is less than the longest distance in the direction of rotation at the end portions of a circular end section. That is, the longest distance of the racetrack in the direction of rotation is less than twice the square root of the combination of the distance between legs, 2S, times the leg width, W_L, plus the leg width squared. $D<D_c$.

An equation for the longest distance, D_p along the direction of rotation for the parabolic shaped end section is be given by:

$$D_p = 2(W_L + S)\sqrt{\frac{W_e}{W_e + T}}$$

Notice that the greater the extension T, the smaller the distance D_p and thus the lower the erosion in the end portions. Additionally, the smaller the width W_e, the smaller the distance, D_p and thus the lower the erosion in the end portions.

Figure 2C is a diagram of a racetrack shape 23 of the present invention with semi-elliptical end sections 24, 25. Elliptical end portions are less pointy than parabolic end portions. An equation for the longest distance, D_{e11} along the direction of rotation for the semi-elliptical shaped end section can be given by

$$D_{e11}=2\sqrt{2W_e T+W_e^{2}}\,\frac{W_L+S}{W_e+T}$$

Thus assuming $W_e=W_L$, $D_{e11} < D_c$ as long as $T>S$.

When that width at the end section W_e is about the same as the width of the legs W_L, the strength of the magnetic field at the end portions can be maintained at close to the strength of the magnetic field in the leg portions and thus the efficiency of the magnetron can be maintained.

The equations given above are approximations for an idealized racetrack plasma. An actual racetrack end section will be only approximately parabolic, semi-elliptical or triangularly shaped. The equations also do not take into account that the ion current density is not uniform across the racetrack width. Finally, the racetrack is on the outside of a cylindrical target rather than a flat surface.

A preferred embodiment of the magnet assembly for the present invention produces a plasma racetrack with end portions that are somewhat parabolic in shape. Diagrams for this preferred embodiment are given in in Figures 4 & 5. Figure 4 is a top view of the preferred embodiment of the magnetron of the present invention. Note that the magnets 56, 59, 58, 60 and 48

are positioned in a tapered fashion about the center axis of the inner magnet section 50. The arrangement of these end magnets is somewhat triangular. It is beneficial that the magnets or magnet in the end portion beyond the center magnet section slopes gradually toward the center axis of the center magnet. The gradual sloping of the magnets or magnet produces a more "pointy" racetrack shape. In this specification, shapes that are less blunt than a rectangular or circular shaped end section, such as triangular, parabolic and semi-ellipse shapes, are defined as having a "gradual slope".

Using multiple rectangular magnets in the end section, such as shown in figure 4, allows for commercially available magnets to be used and thus decreases the cost of the design.

The outer magnets including side magnets 52 and 54 and end magnet 48 along with magnets 56, 58, 59, and 60 are of one orientation while the center magnet 50 is of another.

The preferred magnetic material for the magnet assembly is SAM-15. The properties of SAM-15 is shown in the following table.

Material	B_r(g)	H_c(Oe)	T_c (°C)	η_b (%/°C)	Corr. Res. (in H_2O)
SAM-15	7800	5800	440	-0.04	excellent

where B_r is the remanence, H_c is the coercivity, T_c is the Curie temperature, and η_B is the reversible temperature coefficient.

Figure 5A shows a cross sectional view through Line C-C'. Figure 5B shows a cross sectional view through Line D-D' of Figure 4. Figure 5C shows a cross sectional view through Line E-E' of Figure 4. The distances on Figure 5A-C are shown in inches. The outer diameter of the target in the preferred embodiment is

six inches, although other diameters are easily accommodated.

The geometry of a cylindrical magnetron makes the design of the magnetron to maximize the material utilization slightly easier since it is in effect a one-dimension problem along the axial position since the rotation of the cylindrical target evens out the erosion for different angles. Maximizing the erosion for a planar magnetron is a two-dimensional problem.

In a preferred embodiment, the shunt 66 on which the magnets are placed is made of mild steel.

Figure 6 is a graph of the experimental results from an eroded target of tube radius versus axial position for a prototype of the present invention. Note that at end position 80 which corresponds to the "turn around" position 36c in Figure 3 the erosion is roughly the same as position 82 on Figure 6 which corresponds to the "leg" portion of the racetrack. Bump 84 may be caused by the use of multiple rectangular magnets as the outer magnet rather than a single continuous magnet.

Figure 7 shows the experimental results of the erosion of a prototype cylindrical tube showing over 80% utilization for a supported tube. Point 90 is the point at which the tube erodes through to the backing tube. Point 90 corresponds to the total erosion or "1" position on the graph's horizontal scale. The "0" position on the graph's horizontal scale represents no erosion. The measured utilization was significantly greater than the 60% utilization found with the background art system.

Figure 8 shows a less preferred embodiment of the present invention in which the outer magnet is a cylindrical section whose plane projection looks parabolic. One possible, although currently

impractical, embodiment would be to form outer magnet 102 and inner magnet 100 out of a cylinder or cylindrical tube of magnetic material.

Various details of the implementation and method are merely illustrative of the invention. It will be understood that various changes of details may be made within the scope of the invention which would be limited only by the appended claims.

WHAT IS CLAIMED IS:

1. A cylindrical magnetron comprising:
a rotatable cylindrical target;
an elongated center magnetic section of a first polarity positioned within the rotatable cylindrical target; and
an outer magnet section of a second polarity positioned within the rotatable cylindrical target and arranged around the center magnet section such that spaces are defined between the outer magnet section and the elongated center magnetic section, wherein the elongated center magnetic section and the outer magnet section define a magnetic field to enclose a racetrack shaped plasma around a center area, the racetrack defining an inner edge around a non-plasma center area and an outer edge, the inner and outer edge being at the cylindrical target, the racetrack having roughly parallel leg portions and roughly parabola shaped end portions.

2. The apparatus of claim 1, wherein the inner edge extends into the end portions and the distance between the two intersections of the outer edge with a plane perpendicular to the center axis of the cylindrical target through the center area and one of the end portions is less than the distance between another two intersections of the outer edge with another plane perpendicular to the center axis of the cylindrical target through the leg portion.

3. The cylindrical magnetron of claim 1, wherein the outer magnet section comprises side pieces arranged adjacent to the elongated sides of the center magnet section and end pieces arranged adjacent to the ends of the center magnet section.

4. The cylindrical magnetron of claim 1, wherein the outer magnet section comprises side pieces arranged adjacent to the elongated sides of the center magnet section and wherein the elongated center magnetic section and the side pieces are rectangular in cross-section with the outer faces of the elongated center magnetic section and of the side pieces being approximately tangential to the planes defined through the center of rotatable magnetron and a center line of the outer faces.

5. The cylindrical magnetron of claim 1, wherein the clearance between the outer faces of the center magnetic element and the cylindrical target is approximately the same as the clearance between the outer faces of the side pieces and the cylindrical target.

6. The cylindrical magnetron of claim 1, wherein the magnetic field at the cylindrical magnetron near the ends of the outer magnet section is approximately the same as the magnetic field at the cylindrical magnetron near the center of the outer magnet section in order to help maintain the magnetic bottle effect.

7. A cylindrical magnetron comprising:

a rotatable cylindrical target;

an elongated center magnetic section of a first polarity positioned within the rotatable cylindrical target; and

an outer magnet section of a second polarity positioned within the rotatable cylindrical target and arranged around the center magnet section such that spaces are defined between the outer magnet section and the elongated center magnetic section, wherein the elongated center magnetic section and the outer magnet section define a magnetic field to enclose a racetrack shaped plasma around a center area, the racetrack defining an inner edge around a non-plasma center area and an outer edge, the inner and outer edge being at the cylindrical target, the racetrack having roughly parallel leg portions and roughly triangularly shaped end portions.

8. The apparatus of claim 7, wherein the inner edge extends into the end portions and the distance between the two intersections of the outer edge with a plane perpendicular to the center axis of the cylindrical target through the center area and one of the end portions is less than the distance between another two intersections of the outer edge with another plane perpendicular to the center axis of the cylindrical target through the leg portion.

9. The cylindrical magnetron of claim 7, wherein the outer magnet section comprises side pieces arranged adjacent to the elongated sides of the center magnet

section and end pieces arranged adjacent to the ends of the center magnet section.

10. The cylindrical magnetron of claim 7, wherein the outer magnet section comprises side pieces arranged adjacent to the elongated sides of the center magnet section and wherein the elongated center magnetic section and the side pieces are rectangular in cross-section with the outer faces of the elongated center magnetic section and of the side pieces being approximately tangential to the planes defined through the center of rotatable magnetron and a center line of the outer faces.

11. The cylindrical magnetron of claim 7, wherein the clearance between the outer faces of the center magnetic element and the cylindrical target is approximately the same as the clearance between the outer faces of the side pieces and the cylindrical target.

12. The cylindrical magnetron of claim 7, wherein the magnetic field at the cylindrical magnetron near the ends of the outer magnet section is approximately the same as the magnetic field at the cylindrical magnetron near the center of the outer magnet section in order to help maintain the magnetic bottle effect.

13. A cylindrical magnetron comprising:

a rotatable cylindrical target;

an elongated center magnetic section of a first polarity positioned within the rotatable cylindrical target; and

an outer magnet section of a second polarity positioned within the rotatable cylindrical target and arranged around the center magnet section such that

spaces are defined between the outer magnet section and the elongated center magnetic section, wherein the elongated center magnetic section and the outer magnet section define a magnetic field to enclose a racetrack shaped plasma around a center area, the racetrack defining an inner edge around a non-plasma center area and an outer edge, the inner and outer edge being at the cylindrical target, the racetrack having roughly parallel leg portions and roughly semi-ellipse shaped end portions.

14. The apparatus of claim 13, wherein the inner edge extends into the end portions and the distance between the two intersections of the outer edge with a plane perpendicular to the center axis of the cylindrical target through the center area and one of the end portions is less than the distance between another two intersections of the outer edge with another plane perpendicular to the center axis of the cylindrical target through the leg portion.

15. The cylindrical magnetron of claim 13, wherein the outer magnet section comprises side pieces arranged adjacent to the elongated sides of the center magnet section and end pieces arranged adjacent to the ends of the center magnet section.

16. The cylindrical magnetron of claim 13, wherein the outer magnet section comprises side pieces arranged adjacent to the elongated sides of the center magnet section and wherein the elongated center magnetic section and the side pieces are rectangular in cross-

section with the outer faces of the elongated center magnetic section and of the side pieces being approximately tangential to the planes defined through the center of rotatable magnetron and a center line of the outer faces.

17. The cylindrical magnetron of claim 13, wherein the clearance between the outer faces of the center magnetic element and the cylindrical target is approximately the same as the clearance between the outer faces of the side pieces and the cylindrical target.

18. The cylindrical magnetron of claim 13, wherein the magnetic field at the cylindrical magnetron near the ends of the outer magnet section is approximately the same as the magnetic field at the cylindrical magnetron near the center of the outer magnet section in order to help maintain the magnetic bottle effect.

19. A cylindrical magnetron comprising:

a rotatable cylindrical target;

an elongated center magnetic section of a first polarity positioned within the rotatable cylindrical target, the elongated center magnet section defining an axis; and

an outer magnet section of a second polarity positioned within the rotatable cylindrical target and arranged around the center magnet section, wherein an end portion of the outer magnetic section beyond the center magnetic section slopes gradually toward the axis.

20. The cylindrical magnetron of claim 19, wherein the elongated center magnet section and the outer magnet section are comprised of rectangular block elements,

wherein the ends of the outer magnetic section includes at least two rectangular block elements on opposite sides that are spaced closer to one another without contacting than the rectangular block elements on opposite sides at the center of the outer magnetic section.

21. The cylindrical magnetron of claim 20, wherein the magnetic field at the cylindrical magnetron near the ends of the outer magnet section is approximately the same as the magnetic field at the cylindrical magnetron near the center of the outer magnet section in order to help maintain the magnetic bottle effect.

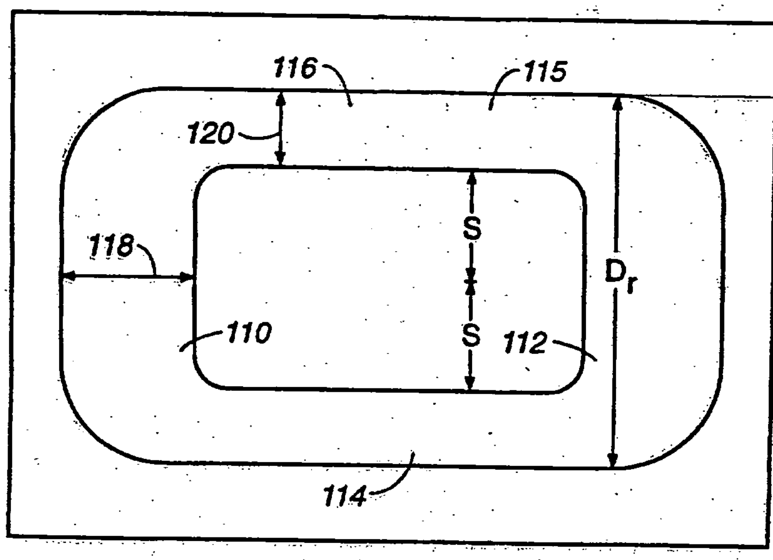


FIG._1
(PRIOR ART)

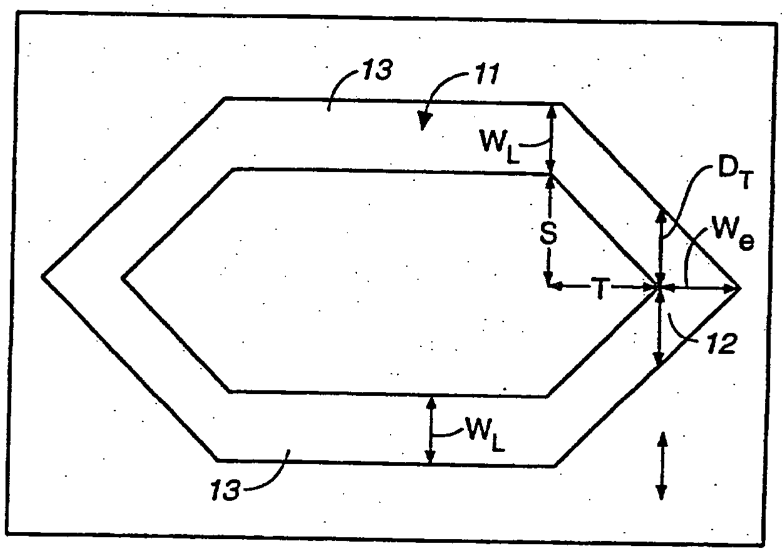
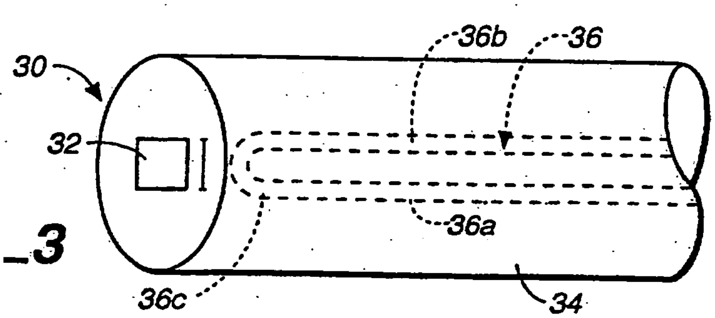


FIG._2A

FIG._3



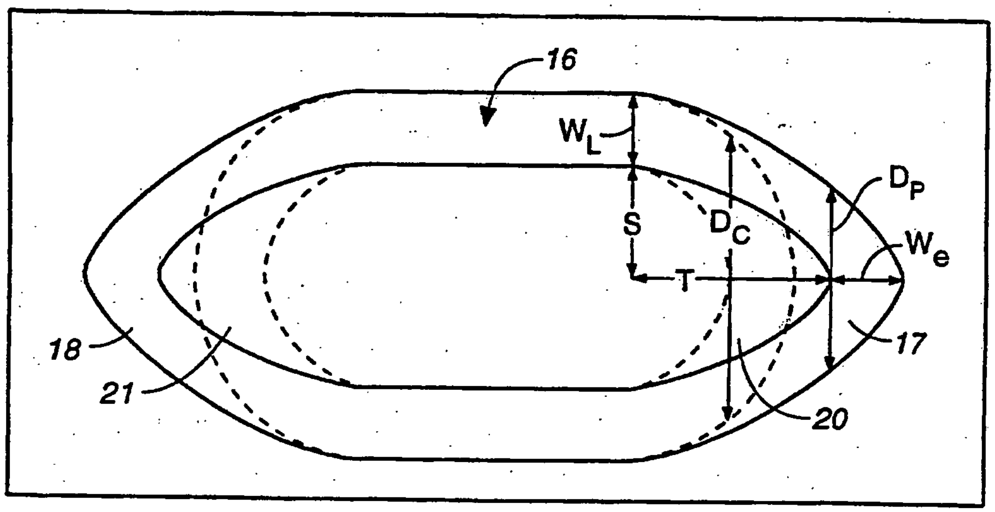


FIG._2B

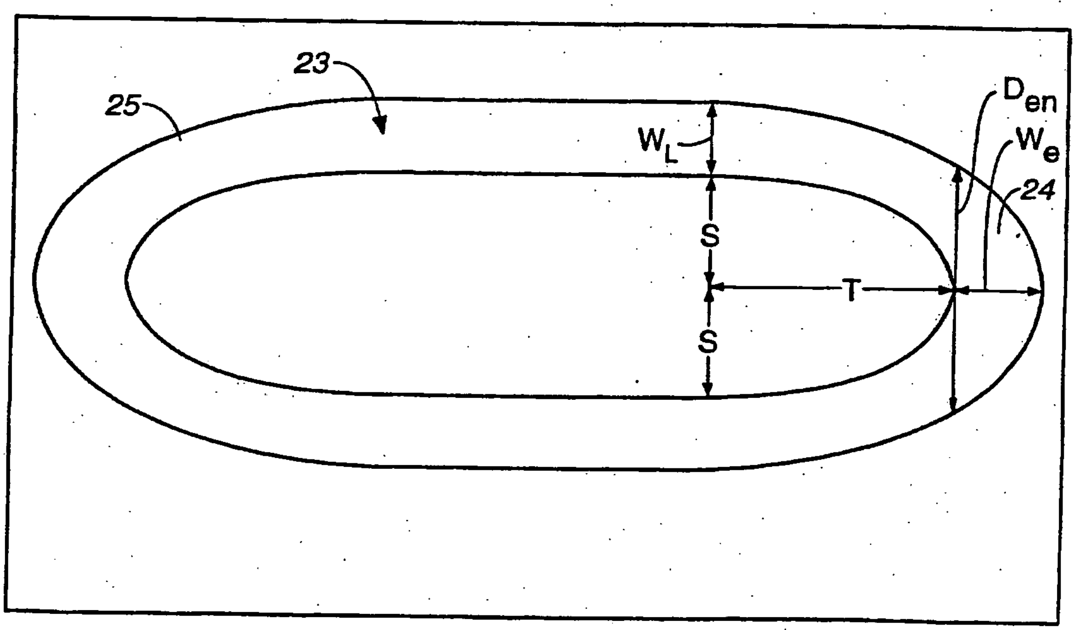


FIG._2C

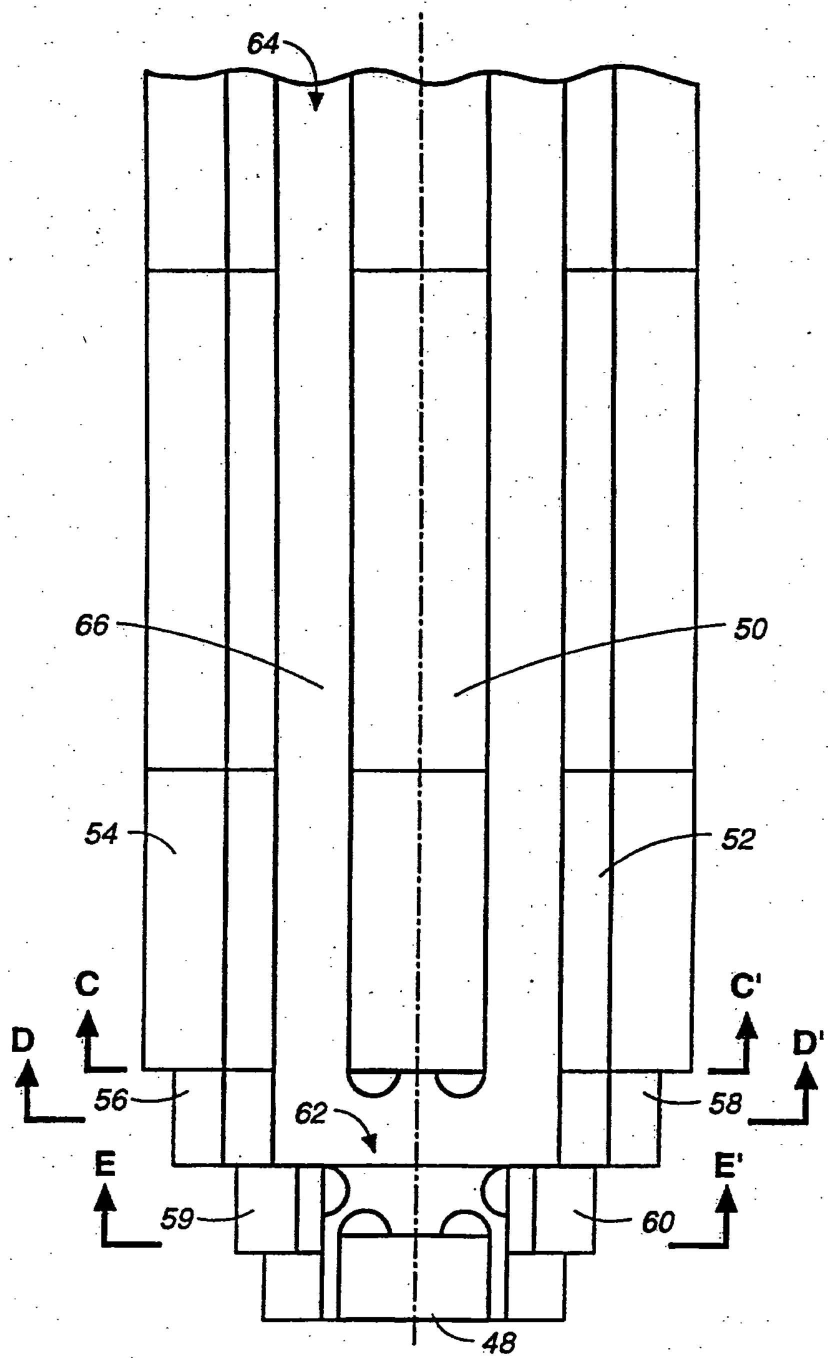


FIG._4

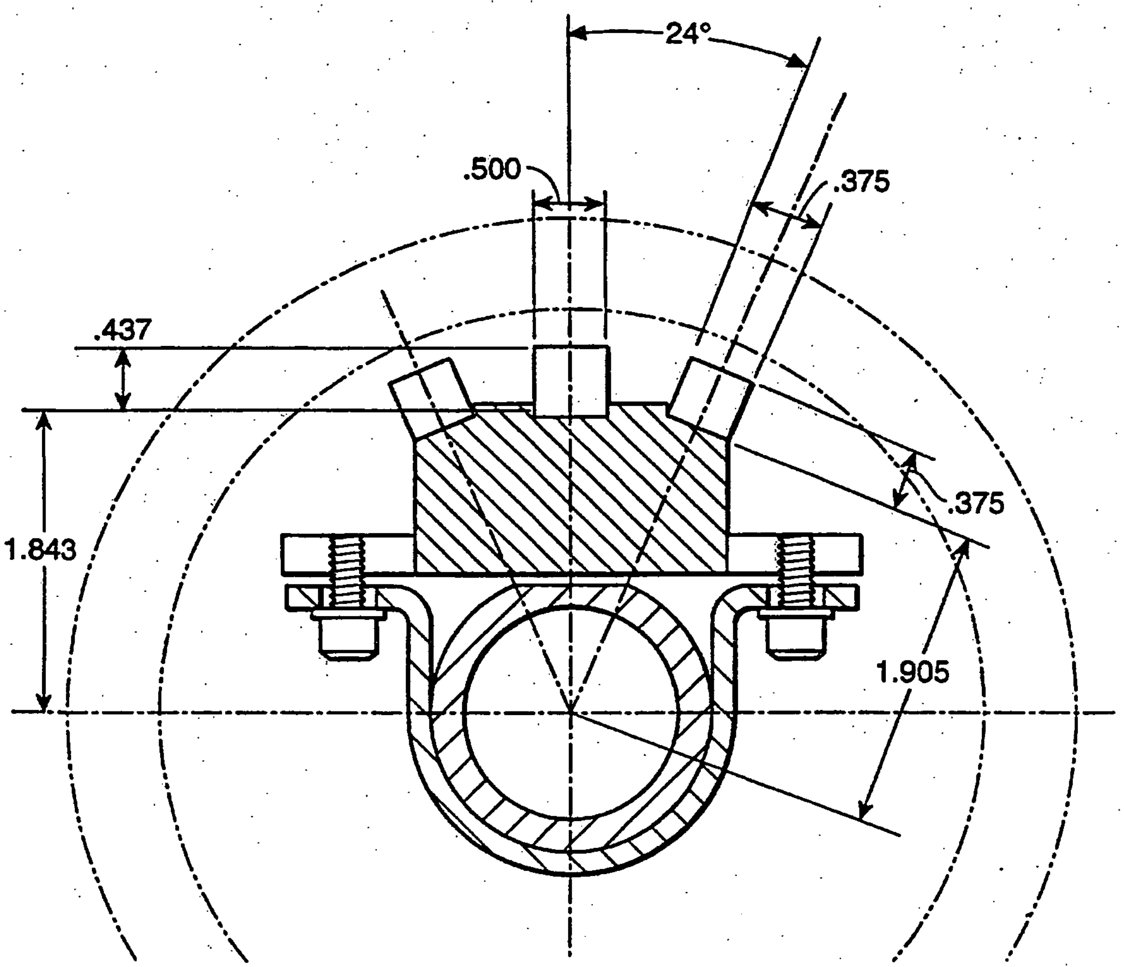


FIG._5A

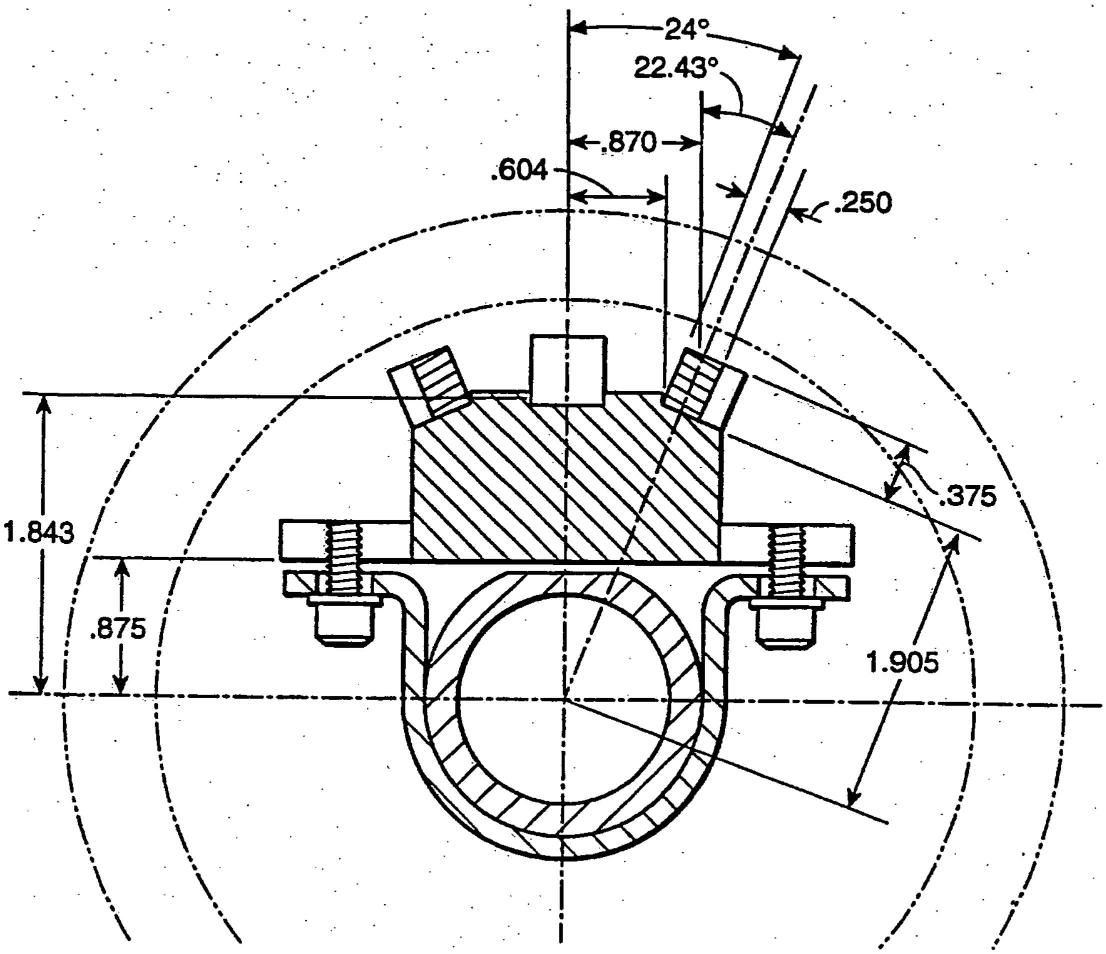


FIG._5B

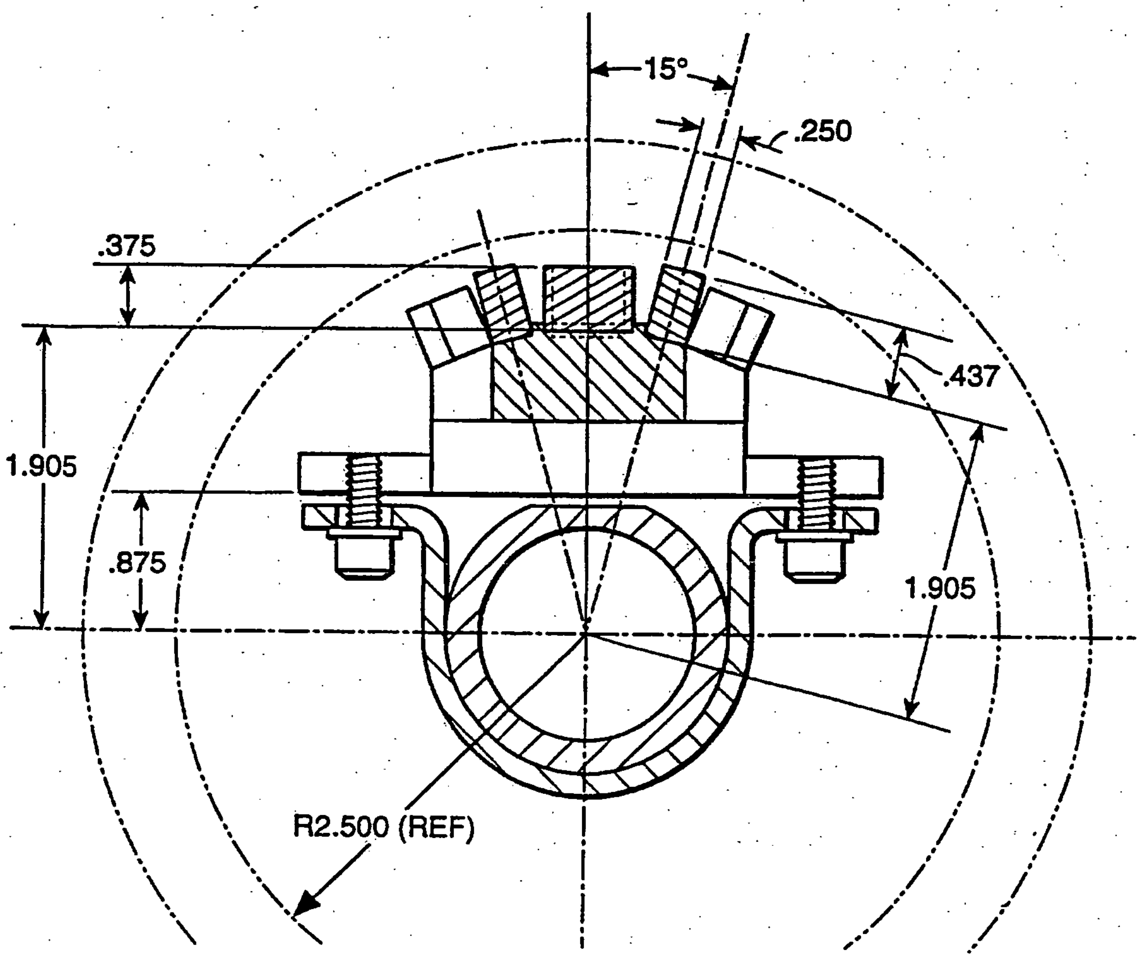


FIG._5C

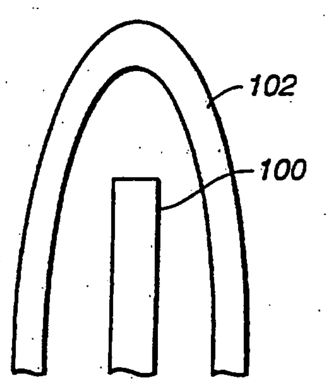


FIG._8

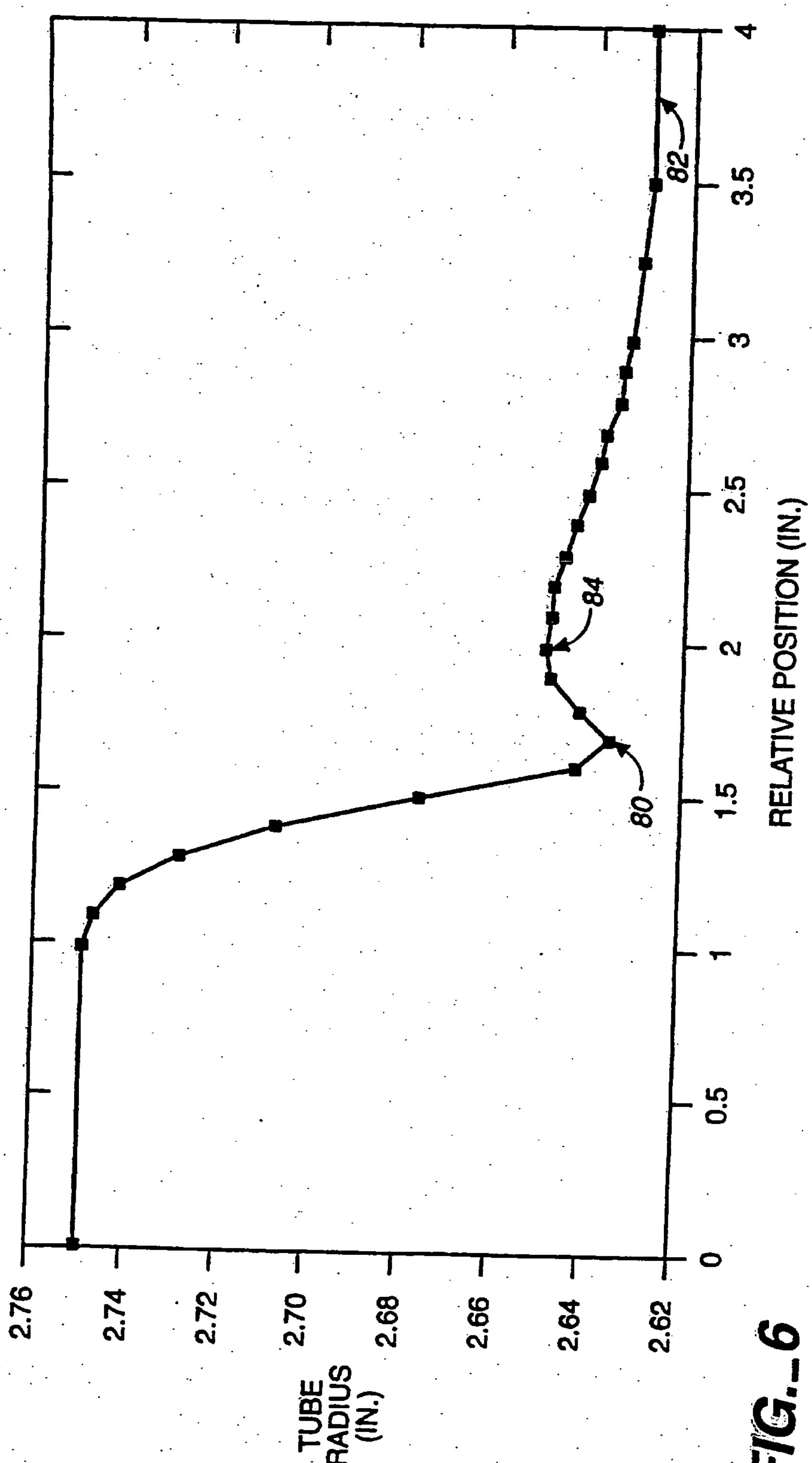

TUBE RADIUS (IN.)
2.76
2.74
2.72
2.70
2.68
2.66
2.64
2.62
RELATIVE POSITION (IN.)
0
0.5
1
1.5
2
2.5
3
3.5
4
80
84
82

FIG._6

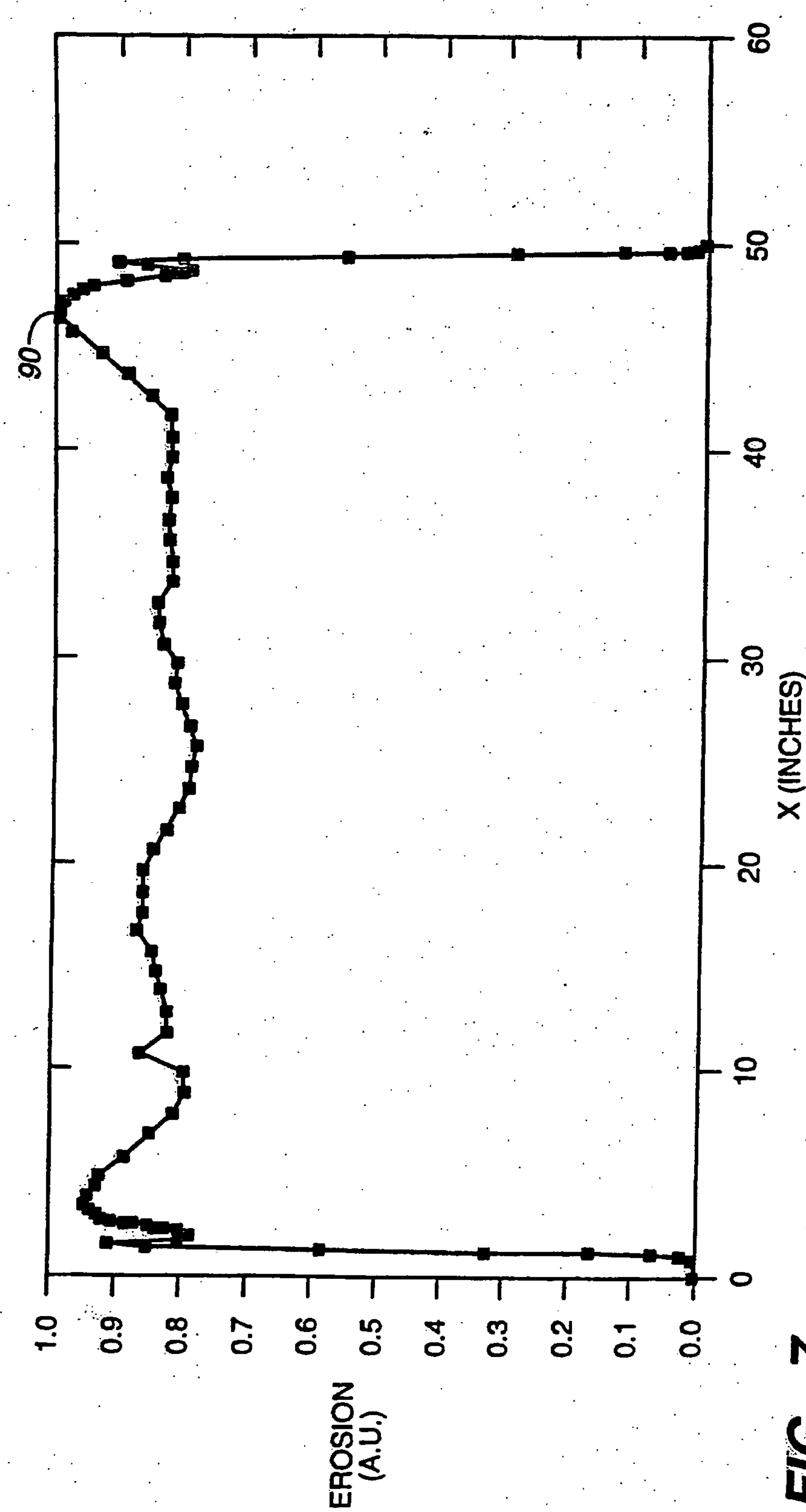

EROSION (A.U.)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
X (INCHES)
90

FIG._7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/00409

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :C23C 14/35
US CL :204/298.22
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 204/298.22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US,A 4,525,264 (Hoffman) 25 June 1985. See Figures 4-5 and 8.	1-21 --- 1-21
A	US,A, 5,364,518 (Hartig et al) 15 November 1994.	1-21
A,P	US,A 5,427,665 (Hartig et al) 27 June 1995.	1-21
A	DE,A, 41 17 367 A1 (Hartig et al) 03 December 1992.	1-21

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 APRIL 1996	29 APR 1996

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Mpanda Roy for AARON WEISSTUCH
Facsimile No. (703) 305-3230	Telephone No. 703-308-3326